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(54) **Process for encapsulation and encapsulated active material system.**

(57) Capsules are formed having a liquifield core while avoiding capsule core gelatin by adding drops of a solution of either an anionic polymer composition or a cationic polymer composition to a solution of an ionic polymer of opposite charge. The drops contain an active ingredient such as a cell or microorganism capable of producing a biologically active product or can contain a biological or chemical composition. The interface of the ionic polymers form a permeable membrane surrounding the liquid drops.

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5 Process for Encapsulation and Encapsulated Active
Material System

This invention relates to a process for encapsulating
biologically active materials such as cells or tissues
10 or biochemically or chemically active compositions and
to the encapsulated system including the active materials.

In biochemical production and biotechnological applicat-
ions, health and viability of active materials such as
15 cells, microorganisms and the like, is important since
these active materials are capable of producing
biologically or biochemically active components that find
a wide variety of use. For example, cells are capable
of producing antibodies, hormones, lymphokines, anti-
20 biotics, interferons and other biochemicals or chemicals.
Mammalian cell lines are grown by being surrounded by
an aqueous medium containing a nutrient in order to
promote the viability and growth of the cells and enables
continued production of the desired microbiological or
25 biological products. It has been proposed to utilize
so-called microcarriers, which are beads having the
appropriate charge and exchange capacity to promote
the growth of the cells thereon in an efficient manner.
The microcarriers themselves are maintained in an
30 aqueous suspension containing the proper nutrient
composition to promote cell growth and production of
the desired microbiological product.

Biological products which are shed or excreted from the
35 cells become admixed with the aqueous suspending

1 composition, which in many cases, is at very dilute concentrations. The subsequent recovery of the desired product is thereby rendered difficult and time consuming.

5 In order to overcome problems associated with microbiological product recovery, it has been proposed to encapsulate cells or microorganisms within a membrane which permits nutrients to be metabolized by the cell or microorganism while retaining the microbiological

10 product produced by the cell or microorganism within the encapsulating membrane. Such processes are disclosed, for example, in U.S. Patents 4,409,331 and 4,352,883. The semipermeable membrane surrounding the biologically-

15 active material has a selected permeability so that substances having a certain molecular weight or below, are allowed to pass through the semi-permeable membrane. By controlling the permeability of the membrane, and by having a knowledge of the approximate molecular size

20 of the desired product, one can confine the product, within the space between the active material and the semi-permeable membrane.

Unfortunately, the process described in U.S. Patent 4,409,331 and 4,352,883 require that the membrane be

25 formed from the surface of an initially formed solid gel bead. This requires that the interior of the bead be subsequently liquefied so that the diffusion of nutrient which is required by the microorganism or cell, will not be hindered thereby to promote formation

30 of the desired microbiological product. Furthermore, liquefaction of the gel is highly desired so that the space between the semi-permeable membrane and the microorganism or cell is available for either cell production or products. Typically, these prior art

35 membranes are formed from a cell suspension in alginate

1 solution which is added dropwise to a calcium chloride
aqueous solution, thereby to form solid gel beads. The
beads then are washed with N-cyclohexylamine ethane
5 sulfonic acid (CHES) and then washed subsequently with
sodium chloride. Thereafter, a polylysine solution is
added to form a polymer complex with the alginate
surface. This surface then is washed with CHES/sodium
chloride, subsequently with calcium chloride and then
10 subsequently with sodium chloride. The membrane then
is incubated and the gel within the membrane is
subsequently liquefied by washing twice with sodium
chloride, incubating, washing with sodium citrate and
sodium chloride, washing with sodium chloride, and then
15 a final wash. Obviously, such a process for forming
encapsulated microbiologically active ingredients is
time consuming and difficult and requires a high level
of laboratory technique in order to successfully
produce the encapsulated cell or microorganism suspended
20 in a liquid medium. Furthermore, during these complicated,
time-consuming steps, the viability, productivity or
other characteristics of the cell may be altered.

It would be highly desirable to provide a means for
encapsulating a microorganism or cell capable of
25 producing a biologically active material which eliminates
the necessity of liquefying a solid carrier in order
to promote mass transfer into and out of the cell
or microorganism. Furthermore, it would be desirable
to provide such an encapsulating means which is capable
30 of drastically reducing the number of steps needed to
form the encapsulated cell or microorganism. In
addition, it would be desirable to provide such an
encapsulating means which permits the formation of
a membrane capable of having a permeability over
35 a wide range, which permits the isolation or selective

1 separation of a wide variety of biologically or chemically
active molecules.

5 In accordance with this invention, cells, microorganisms,
or the like, capable of producing a biologically active
composition or biochemicals such as enzymes or hormones
or the like or nonbiochemical compositions such as
substrates, reactants, or catalysts are encapsulated by
10 a polymer complex comprising the combination of an anionic
polymer and a cationic polymer. The term "active mater-
ial" is used herein to include cells, microorganisms or
the like which produce a biologically active composition
or a composition such as an enzyme, hormone, antibody,
15 antibiotic insecticide, catalyst, substrate or reactant
or the like which active material is to be encapsulated
in accordance with this invention. The active material
is suspended in an aqueous solution of either one of the
cationic polymer or the anionic polymer composition.
20 The polymer composition containing the active material
then is formed into non gel liquid particles and is
added to the other polymer such as in the form of drops
from a capillary tube or a spray or the like to form
capsules comprising a membrane surrounding a liquid core.
25 The active material is housed within the interior of the
membrane suspended in the liquid core. The capsules then
are washed and ready to use or then can be stored in an
appropriate medium until use. The permeability of the
membrane is controlled by controlling concentration of
30 the cationic and anionic polymers in the solution used
in the preparation of the capsule, the pH of the aqueous
solutions in which the cationic polymer or anionic
polymer are prepared, the presence or absence of counter-
ions in each solution, and the molecular weight of the
35 anionic polymer and the cationic polymer as well as
the selection of specific polymers.

1 The process of this invention eliminates the need for
liquefying the core of the capsule containing the active
ingredient and also eliminates the need for multiple
washing steps with a variety of reagents which may
5 adversely affect the biological, biochemical or chemical
activity of the active ingredient to be encapsulated.
In addition, the process of this invention is useful
with a wide variety of biologically active molecules
over a wide molecular type and weight range, since the
10 permeability of the membrane formed around the capsule
can be varied widely. Thus, it is possible to separate,
isolate or selectively segregate biologically active
compounds of varying nature by controlling the perme-
ability of the membrane.

15 In accordance with this invention, an active material
comprising or being capable of producing biologically
active compositions is encapsulated within a membrane
capable of permitting transport of a variety of compounds
20 such as a nutrient for a cell to the active material
and capable of selectively containing, within the mem-
brane, the compound produced. The active ingredient can
be a cell, microorganism, tissues or chemical or bio-
chemical reactants. Representative suitable cells
25 include fused cells, eg. hybridoma cells, or genetically
modified cells produced by recombinant DNA technology
and lymphocyte cells capable of producing antibodies
or microorganisms for fermentation.

30 In addition, microorganisms such as bacteria, can be
encapsulated in accordance with this invention.
Furthermore, biologically active compositions such as
enzymes, hormones, ^{antibiotics,} /antibodies or the like can be
encapsulated so that they can be controllably released
35 through the membrane or retained therein if desired.

1 The encapsulated active ingredient is enclosed by the
 membrane, which also can contain an aqueous medium which
 includes nutrients for the active ingredient. The
 aqueous medium also is capable of dissolving or sus-
 5 pending the microbiologically active material produced by
 the active ingredient without degrading it. The perme-
 ability of the membrane is such as to permit passage
 of nutrients from a medium surrounding the membrane into
 the aqueous medium enclosed by the membrane, and so that
 10 the microbiologically active composition can be produced
 by the active ingredient.

The active ingredient first is suspended in an aqueous
 solution of either (a) one or more anionic polymers or
 15 (b) one or more cationic polymers. The anionic polymers
 or cationic polymers chosen are formed of molecularly
 repedative segments linked together which here are
 either positively charged or negatively charged segments
 distributed along the chain or on substitutions distribut-
 20 ed along the chain. The concentration of charged segments
 is such as to permit electrostatic interaction and en-
 tanglement of the polymers when they are contacted
 together thereby to form the membrane. The resultant
 suspension then is sprayed into or added dropwise or the
 25 like as liquid particles to the other polymer so that
 a membrane is formed at the interface between the
 anionic polymer and the cationic polymer. When the
 interface between the two oppositely charged polymers
 encloses the active ingredient, the active ingredient
 30 thereby becomes encapsulated. Representative suitable
 anionic polymer include alginate, carragenen,
 hyaluronic acids, carboxymethylcellulose, xanthan,
 furcellaran and, sulfonated organic polymers, usually
 in salt form, eg, sodium salt. Representative suitable
 35 cationic polymers include chitosan, polylysine,

1 polyethylamine and polyvinylamines as well as other
amine or imine containing polymer which is capable of
coacting with an anionic polymer to form a membrane. The
preferred anionic polymers are alginate, or carragenan.
5 The preferred cationic polymers are chitosan, or poly-
lysine. The droplets of the charged polymer containing
the active ingredient can be regulated in order to
regulate the size of the final encapsulated product.
Typical encapsulated products have a size within the
10 range of about 50 microns and 5000 microns. When cells
are to be encapsulated, the capsule has a size which
permits oxygen transfer to those cells that require
oxygen for vitality and has a size sufficiently small
to afford efficient isolation of the desired cell product,
15 typically between about 400 and 800 microns.

The permeability of the membrane formed by the inter-
action of the anionic polymer and the cationic polymer
is controlled by controlling the relative concentration
20 of the two oppositely charged polymers, their concentrat-
ion in the individual aqueous media, the pH of each of
the polymer solutions, the molecular weights of the
polymers and presence or absence of counter-ions in
either of the solutions. By the term "counter-ions" is
25 meant ions which interact with the charged portion of
the polymer in order to reduce interaction of that
polymer with the oppositely charged polymer. For
example, calcium ion interacts with carboxyl ion on
the anionic polymer. The calcium ion can be removed
30 with phosphate ion. Increased polymer concentration
usually results in decreased permeability. A decrease
in the pH of the anionic polymer composition results
in increased concentration of hydrogen ion thereby to
form reactive cations on the cationic polymers having
35 amine or imine groups. The achievement of a membrane

1 having a desired permeability can be determined by
varying the process parameters and incorporating a
mixture of compounds of anions molecular weight and size
in the droplets or spray. The aqueous medium outside the
5 capsules thus produced can be assigned for the presence
of these compounds so that the molecular weight/molecular
size cut-off level of the membrane is thus determined.

This invention also provide capsules having a normal
10 membrane structure having improved mechanical properties
as compared to the capsules of the prior art. Membranes
produced from a gel composition and which are subsequent-
ly liquified have reduced strength. This is due primarily
to the fact that a large proportion of the polymer chains
15 becomes oriented towards the interior of the capsule
during gelation rather than in the plane of the membrane.
During liquification of the gel, these portions of the
polymer chain do not become reoriented into the plane
of the membrane and therefore do not contribute to
20 membrane strength. In contrast, in this invention, the
ionic portions of the anionic and cationic polymers need
not be encumbered with counter ions so that they are
free to react with each other along the entire chain
length where the different polymers come into reactive
25 contact. By operating in this manner, larger chain
lengths of the polymers are oriented in the plane of
the membrane. In one particular aspect of this invention,
it is possible to have the anionic polymer oriented
on the outside of the membrane rather than on the inside
30 of the membrane. Thus, for example, alginate can
comprise the outer membrane surface. The result is not
possible with prior art processes since the alginate
is required to form the initial gel bead. Thus, this
invention provides the user with much greater flexi-
35 bility in forming the capsule. In another particular

1 aspect of this invention, multi-membrane walls can be
formed thereby providing membranes with greater strength
as compared to capsule of the prior art. This is
accomplished by forming the capsule with the anionic
5 polymer chain on the outside of the membrane by the
process set forth above. The capsules then are separated
from the surrounding aqueous medium by any convenient
method such as filtration or centrifugation. The capsules
then are mixed with a solution of anionic polymer and
10 a crosslinking divalent metal ion. For example, in the
case of alginate as the anionic polymer, calcium ion or
barium ion can be used as the crosslinking divalent ion
to form an outer membrane of alginate polymer.

15 After the encapsulated active ingredients are produced
in accordance with the above-described process, then
they can be separated from the aqueous medium where
they are suspended, and then reintroduced into an aqueous
medium which contains the nutrients for the active
20 ingredient, so that the microbiologically active
compound can be produced. On the other hand, the
nutrients can be added to the suspension of encapsulated
active ingredients without prior separation thereof.

25 The following examples illustrate the present invention
and are not intended to limit the same.

Example I

30 An alginate solution comprises 0.75 percent--1 percent
w/v sodium alginate and 150 mM NaCl was added dropwise
to a chitosan solution. The chitosan solution comprised
0.05--0.10 gr/dl chitosan, 117 mM NaCl, 0.01 M CaCl_2
and 0.01 M HCl. The chitosan solution had a pH of
6.5. The alginate solution was added dropwise to the
35 chitosan solution to form capsules which were incubated

1 in the chitosan solution for about one minute. Samples
of the chitosan solution containing the capsules were
separated by centrifugation or by filtration on a
centered glass filter, washed with water and transferred
5 separately to a phosphate buffer solution, a saline
solution, distilled water or a cell culture medium
comprising Dulbecco's Modified Minimum Essential
Medium, 5 % Fetal Calf Serum and 5 % Calf Serum and were
found to be surprisingly stable. In addition, the cap-
10 sules were found to be able to sustain centrifugation
at a level at least as high as about 2000 RPM for 10
minutes. In this example, it is preferred that the
alginate solution have a viscosity higher than about
3.0 centistokes while a chitosan solution preferable
15 has a viscosity of at least about 1.5 centistokes.

Example II

Following the procedure of Example I, capsules were
formed by adding a chitosan solution dropwise to an
20 alginate solution. The chitosan solution comprised
1.5 percent w/v chitosan, 2.5 percent citric acid and
0.07 M CaCl_2 . The alginate solution comprised either
1.1 percent w/v sodium alginate and 0.5 percent sodium
sulfat, or a solution comprising 1 percent w/v sodium
25 alginate. As in Example I, the capsules were found to
be stable in phosphate buffer, saline, water and cell
culture medium, and were able to sustain centrifugation
at a level of about 2000 RPM for at least 10 minutes.
The core of the capsules is rendered more fluid-like
30 and less solid-like by lowering the concentration of
calcium chloride in the chitosan solution.

Example III

Following the procedure of Example I, capsules were
35 formed by adding chitosan solution dropwise in an

1 alginate solution to obtain capsules with a liquid core.
The chitosan solution utilized contained between 0.1
percent and 1.5 percent w/v chitosan, 0.05 M NaCl and
between 0.006 M and 0.2 M CaCl_2 and a pH rate ranging
5 between 5.5 and 6.6. The alginate solution ranged between 0.1 percent and 1.0 percent sodium alginate.

As in Examples I and II, the capsules produced were found
to be stable in phosphate buffer, saline, water and in
10 the cell culture medium. As shown in Table I, the
rupture strength of the capsules produced by this
invention can be increased by treating them with a
divalent ion after they are formed. Alternatively, the
divalent ion can be added with an ionic polymer with
15 which it does not interact to form a gel. The diffusion
properties can also be controlled by solution conditions
which influence the molecular configuration or the
charge density of the polymers. The rupture strength
of various capsules made in accordance with the
20 procedures set forth in Example III is shown in Table I.

Table I Effect of divalent cations on the rupture strength of the capsules

Cation	Capsule Preparation	Rupture Strength g/cm ²
25 Ca ⁺²	1.35 % chitosan, 0.05 N in 0.5 % alginate; no treatment of capsules	8
30 Ca ⁺²	Prepared as above + treatment of capsules in 0.1 M CaCl_2 for 5 minutes	743
Ba ⁺²	1.35 % chitosan, 0.05 M BaCl_2 dropped in 0.5 % alginate; no further treatment	696
35 Ba ⁺²	Prepared as above + treatment of capsules in 0.1 M BaCl_2 for 5 minutes	1609

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15 C l a i m s

1. A process for producing a capsule having a liquid
core from ionic polymers while avoiding gelation
of said core which comprises:
20 Forming a liquid droplet from an aqueous solution
of a first ionic polymer selected from the group
consisting of at least one anionic polymer and at
least one cationic
polymer and by contacting said droplet with a
25 solution of at least one second ionic polymer, said
second ionic polymer having an ionic charge opposite
from said first ionic polymer and reacting said
first and second polymer in contact with each other
thereby to form a membrane encapsulating said
30 droplet.

2. A process of claim 1 wherein said droplet contains
an active material wherein said active material
may be one of the group consisting of living cells
35 or microorganisms or hybridoma cells or lymphocytes

- 1 or bacteria or a biologically active compound or
an enzyme or a hormone.
- 5 3. A process for producing a product from a living cell
which comprises encapsulating said cell by the
process of claim 1 and controlling the permeability
of said membrane to prevent said product from
10 permeating said membrane, collecting said encapsulated
cell, rupturing said membrane and recovering said
product, wherein said cell may be one of the group
consisting of a hybridoma or a lymphocyte cell.
- 15 4. A process of claim 1, 2 or 3, wherein said anionic
polymer is selected from the group consisting of
alginate and carragenan and said cationic polymer
is selected from the group consisting of chitosan
and polylysine.
- 20 5. A process of anyone of claims 1 to 4, wherein a
second membrane is formed by cross-linking a second
anionic polymer to the anionic polymer portion of
said first polymer by adding a divalent metal cation
and said second anionic polymer after said first
25 membrane is formed, said metal cation may be
selected from the group consisting of calcium,
barium and mixtures thereof.
- 30 6. A capsule comprising a polymeric membrane surrounding
a liquid core wherein said membrane is formed by the
interaction of at least one anionic polymer with at
least one cationic polymer and wherein molecular
chains comprising said polymer are oriented
35 substantially within said membrane.

- 1 7. The capsule of claim 6, wherein said cationic
polymer forms the inner surface of said membrane
adjacent liquid core.
- 5 8. The capsule of claim 6, wherein said anionic polymer
forms the inner surface of said membrane adjacent
said liquid core.
- 10 9. The capsule of claim 6, wherein said liquid core
contains an active material, wherein said active
material may be one of the group consisting of
living cells, hybridoma cells and lymphocyte cells.
- 15 10. The capsule of anyone of claims 6 to 9, wherein
said anionic polymer is selceted from the group
consisting of alginate and carragenan or wherein
said cationic polymer is selected from the group
consisting of chitosan and polylysine.
- 20 11. The capsule of anyone of claims 6 to 10, which
includes a second membrane formed by cross-linking
the anionic polymer to the anionic polymer portion
of said polymeric membrane with a divalent metal
ion, wherein said divalent metal ion may be selected
25 from the group consisting of calcium, barium and
mixtures thereof.
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